Software Defined Radio Developments and Verification for Space Environment on NASA's Communication Navigation, and Networking Testbed (CoNNeCT)

Richard Reinhart

NASA Glenn Research Center, Cleveland, Ohio

Co-Investigators: Thomas Kacpura, Sandra Johnson, James Lux

Wireless Innovation Forum Technical Conference

November 2011

SCAN Testbed
Science & Technology Goals & Objectives

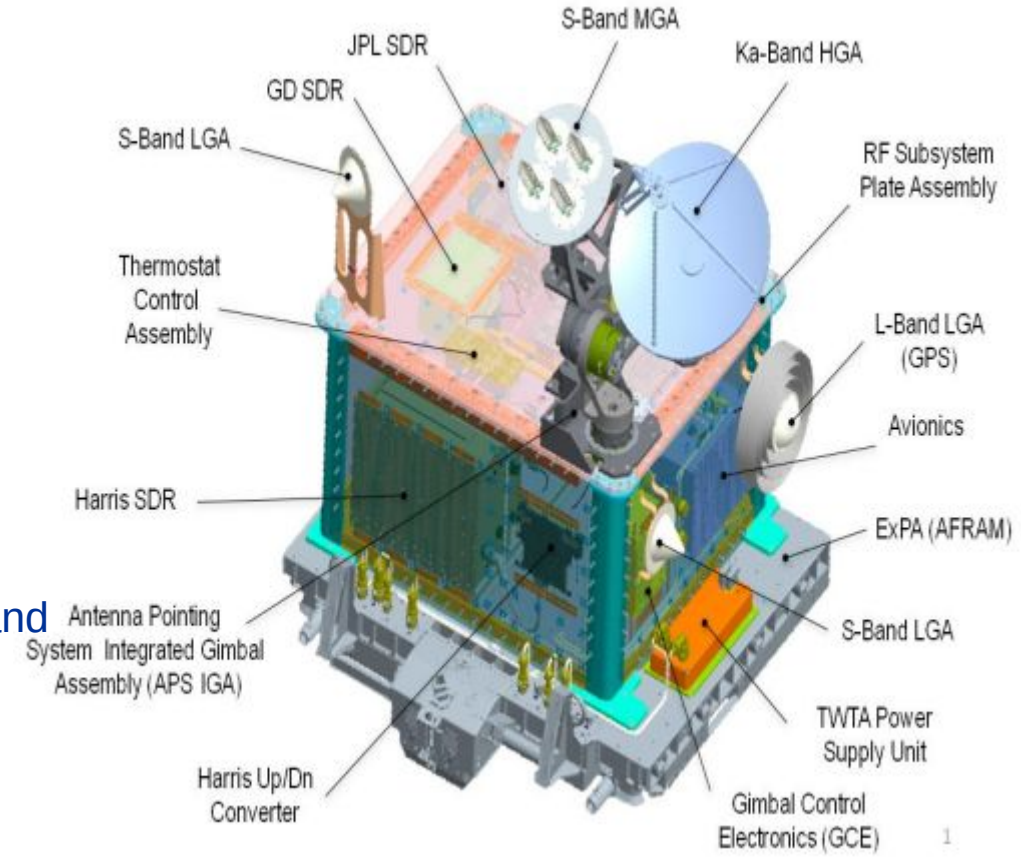
- **INVESTIGATE the APPLICATION of SDRS TO NASA MISSIONS**
  - Mission advantages and development/verification/operations aspects
  - On-Orbit Reconfiguration
  - More process intensive functions within the radio subsystem

- **SDR TECHNOLOGY DEVELOPMENT**
  - SDR Platforms to TRL-7
  - SDR platform hardware & waveform compliant to STRS, Foster Agency adoption
  - Understand/characterize space effects and SDR performance

- **VALIDATE FUTURE MISSION OPERATIONAL CAPABILITIES**
  - Capability representative of future missions
    - Comm data rate, performance, navigation/ GPS, networking/routing
  - Understand SDR performance (reliability, SEE, telemetry, instrumentation)
  - Multiple and simultaneous RF Links (Ka-band, S-band, L-band/GPS)
  - Experimenter sw applications (On-board networking , DTN, routing, and security applications)

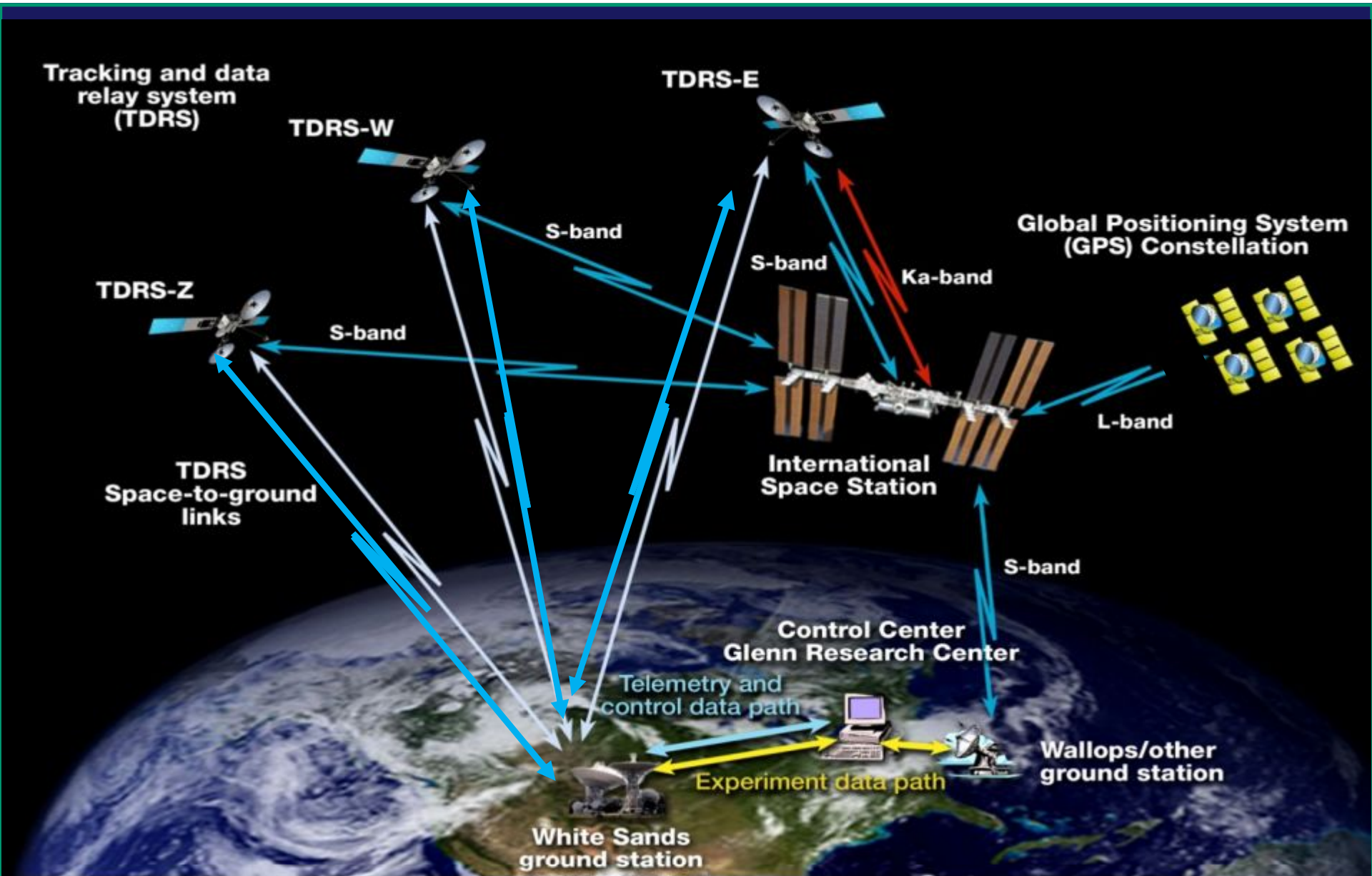
Flight System Overview

- Communication System
  - SDRs
    - 2 S-band SDRs (1 with GPS)
    - 1 Ka-band SDR
  - RF
    - Ka-band TWTA
    - S-band switch network
  - Antennas
    - 2 - low gain S-band antennas
    - 1 - L-band GPS antenna
    - Medium gain S-band and Ka-band antenna on antenna pointing subsystem.
  - Antenna pointing system.
    - Two gimbals
    - Control electronics
- Flight Computer/Avionics
- Flight enclosure provides for thermal control/radiator surface.



Total mass ~746 lb

SCAN Testbed System Architecture



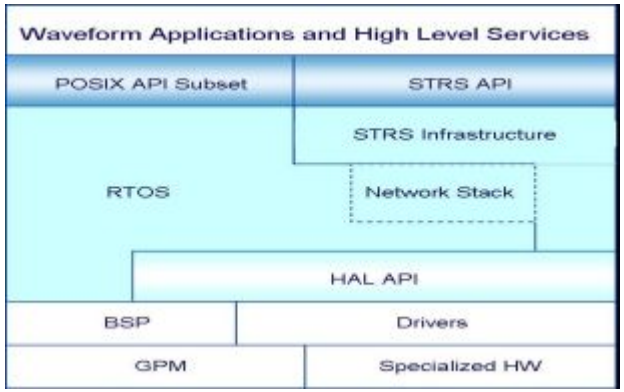
Radio Introduction

- Assess development cost and risk for space SDRs
  - Gain lessons learned for development, verifications, operations
  - Highlight routine on-orbit reconfigurability
- Infuse STRS into radio product lines
  - Assess development cost and risk for STRS compliance
  - Enable multiple providers of STRS radios
- Look to move more functions into the radio (e.g. framing traditionally done in flight computer)
- Leverage existing products to meet NASA needs
  - SDR (tech) developments used cooperative agreements to share cost/risk
- Capability driven by NASA needs, schedule, cost
  - Existing interfaces
  - S-band, Ka-band, GPS (L5)

SDRs are the core of the CONNECT Communication System

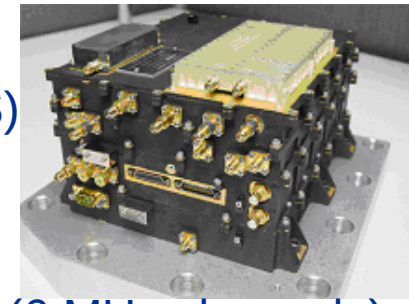
STRS SDRs

- Advance STRS/SDR Platforms to TRL-7
- Single standard on SDR and WF



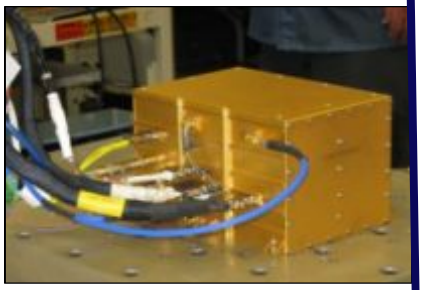
- Compliance verified w/
  -tools
  -inspection
  -observation

JPL/L-3 CE



- L-band receive (GPS)
- S-band SDR
- Tx: 2.2-2.3 GHz, 7W
- Rx: 2.025-2.12 GHz, (6 MHz channels)
- Virtex II, Sparc Processor (100 MIPS) , RTEMs OS, EDAC

General Dynamics

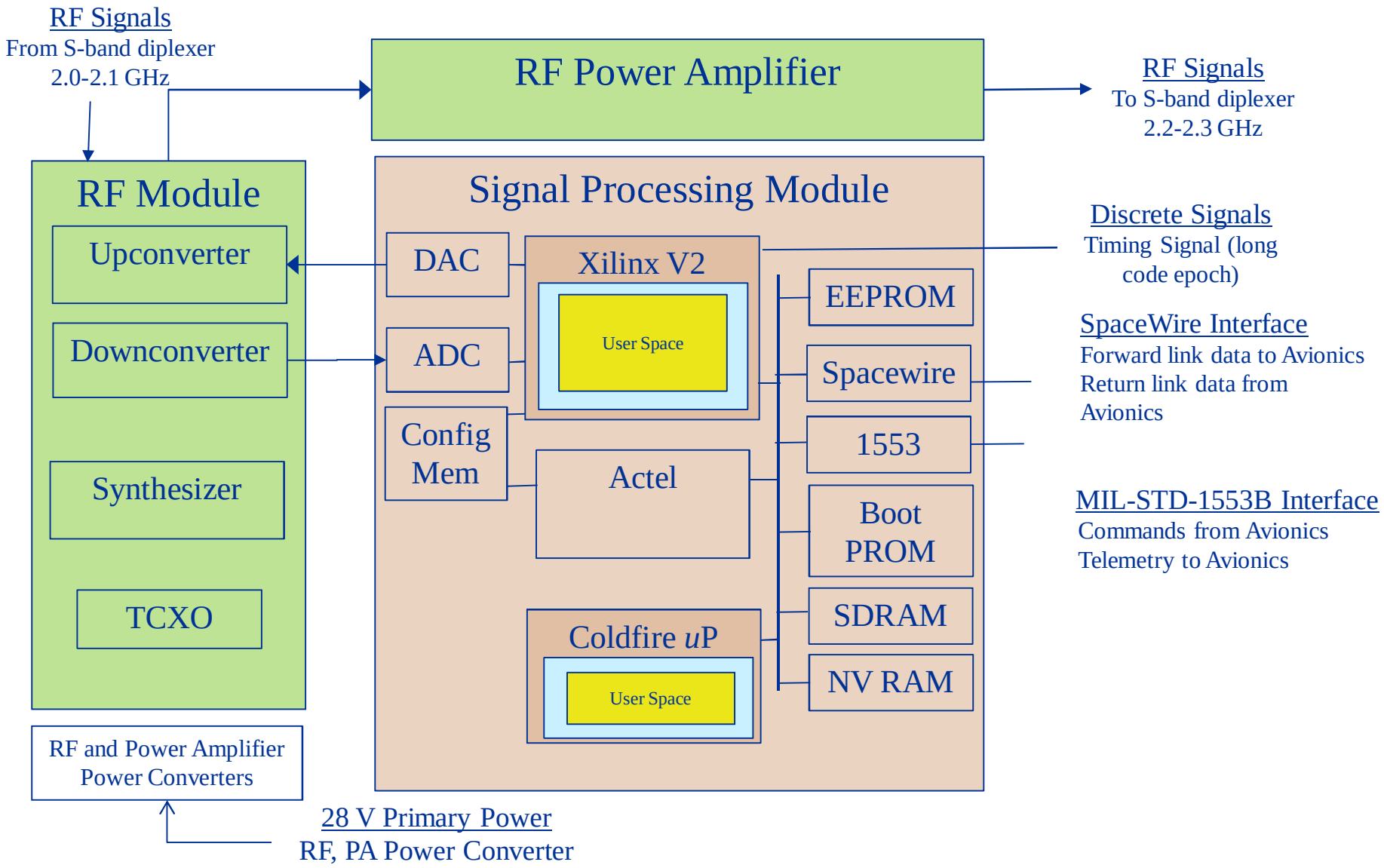


- S-band SDR
- Tx: 2.2-2.3 GHz, 8W
- Rx: 2.025-2.12 GHz (6MHz channels)
- Virtex II, ColdFire Processor (60 MIPS), VxWorks OS, CRAM (Chalcogenide RAM) Memory

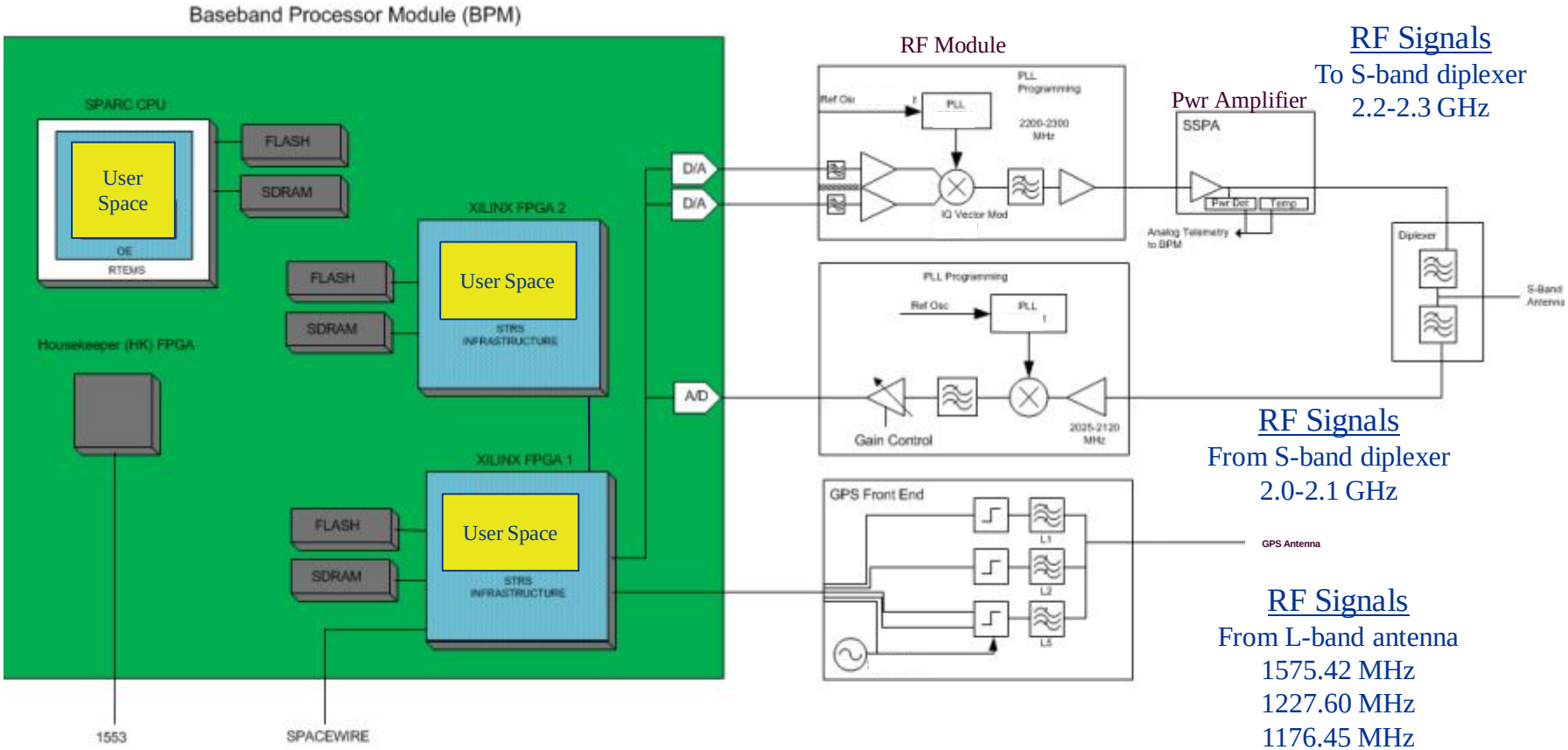
Harris

- Ka-band SDR
- Tx: 25.650 GHz, 225 MHz
- Rx: 22.680 Ghz, 50 MHz
- Virtex IV, AiTech-PowerPC Processor (~700 MIPS), DSP (1 GFLOP), VxWorks OS, Scrubbing ASIC
- First Ka-band transceiver
- GSE – Avionics Comm/Telem Simulator

GD SDR Hardware Architecture



JPL SDR Hardware Architecture



RF Signals
To S-band diplexer
2.2-2.3 GHz

RF Signals
From S-band diplexer
2.0-2.1 GHz

RF Signals
From L-band antenna
1575.42 MHz
1227.60 MHz
1176.45 MHz

MIL-STD-1553B Interface
Commands from Avionics
Telemetry to Avionics

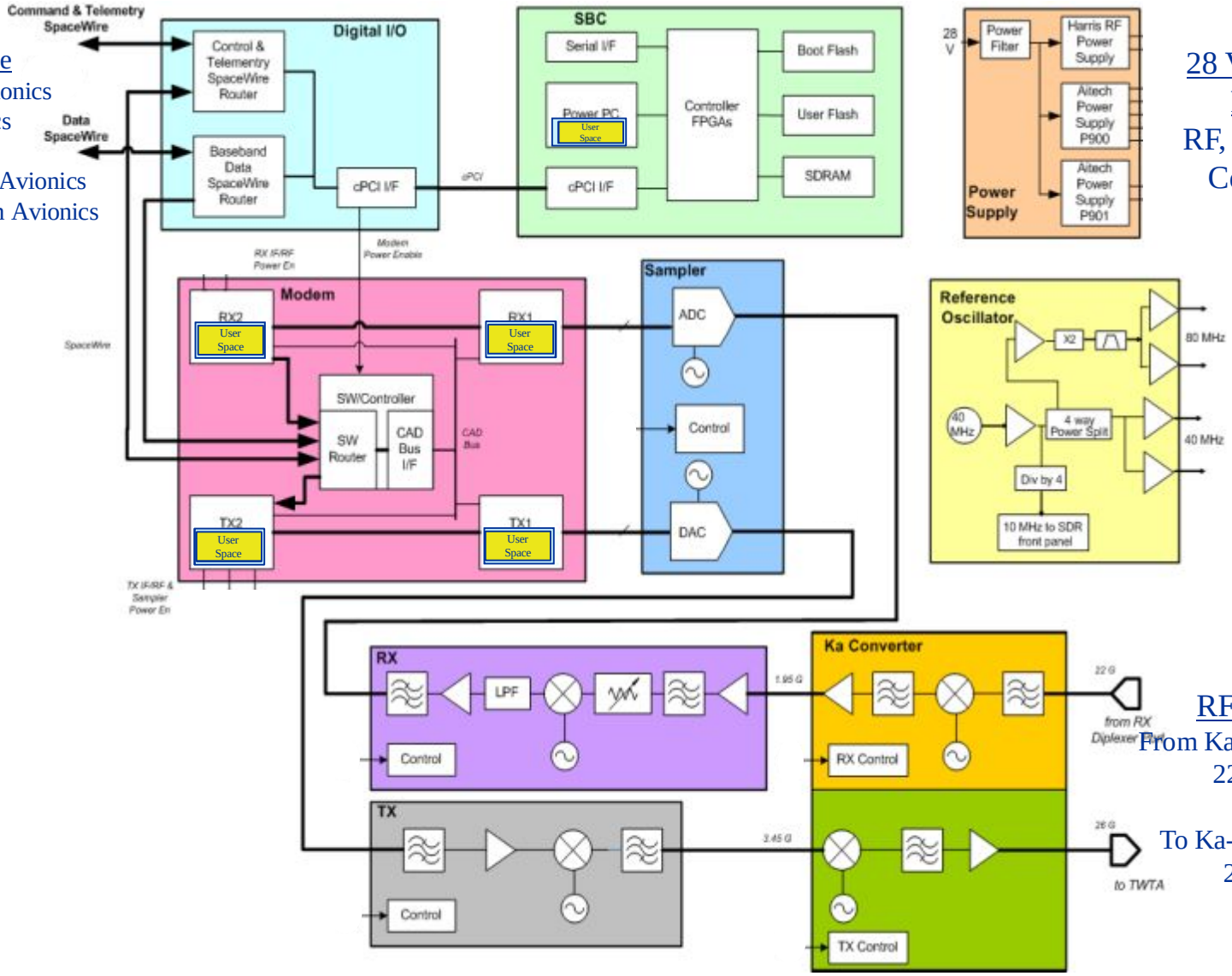
SpaceWire Interface
Forward link data to Avionics
Return link data from Avionics

28 V Primary Power
RF, PA Power Converter

Harris SDR Hardware Architecture

SpaceWire Interface
Commands from Avionics
Telemetry to Avionics

Forward link data to Avionics
Return link data from Avionics

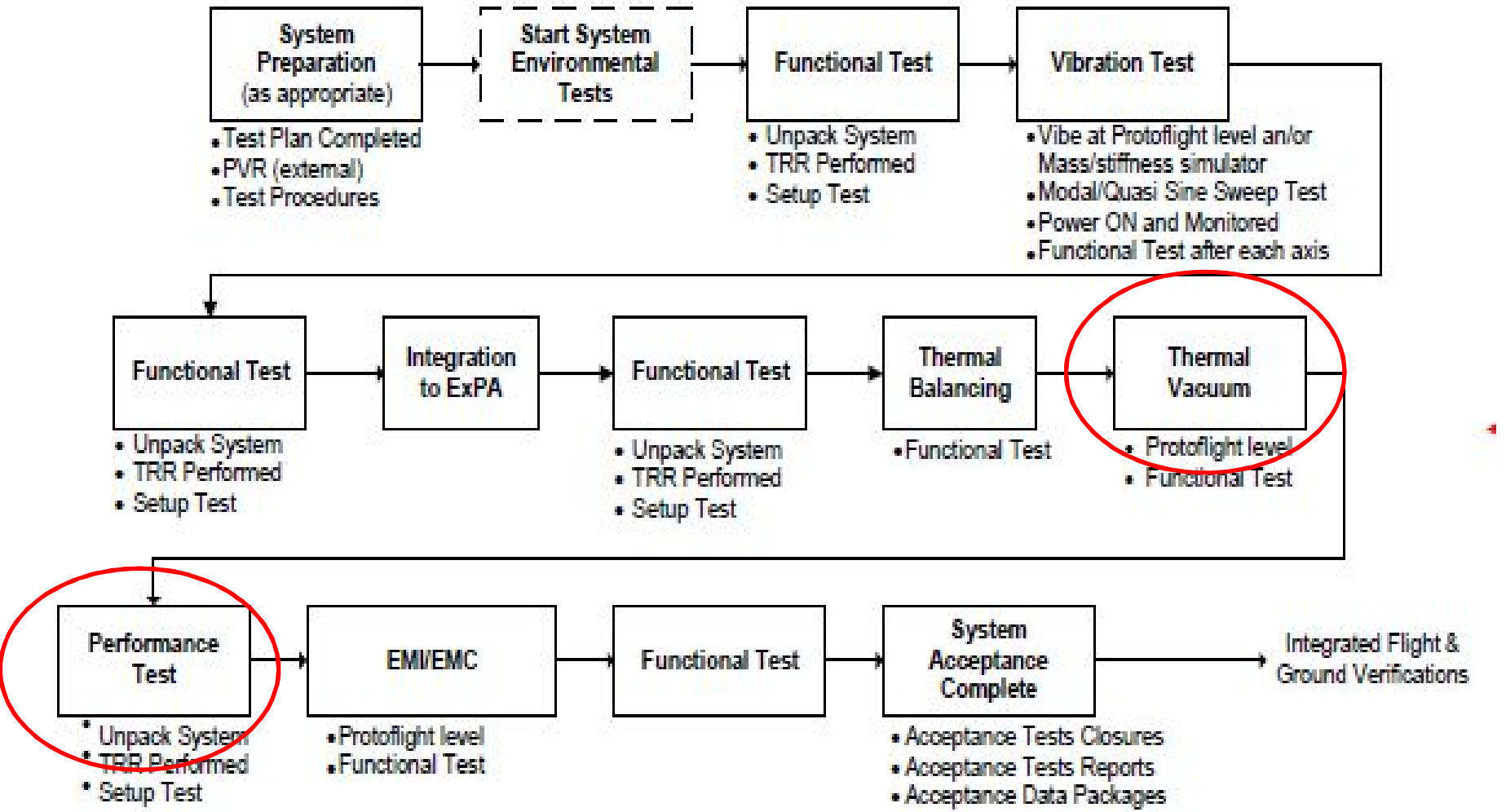


28 V Primary Power
RF, PA Power Converter

RF Signals
From Ka-band diplexer
22.0 GHz

To Ka-band TWTA
26 GHz

Environmental Verification / Validation Approach



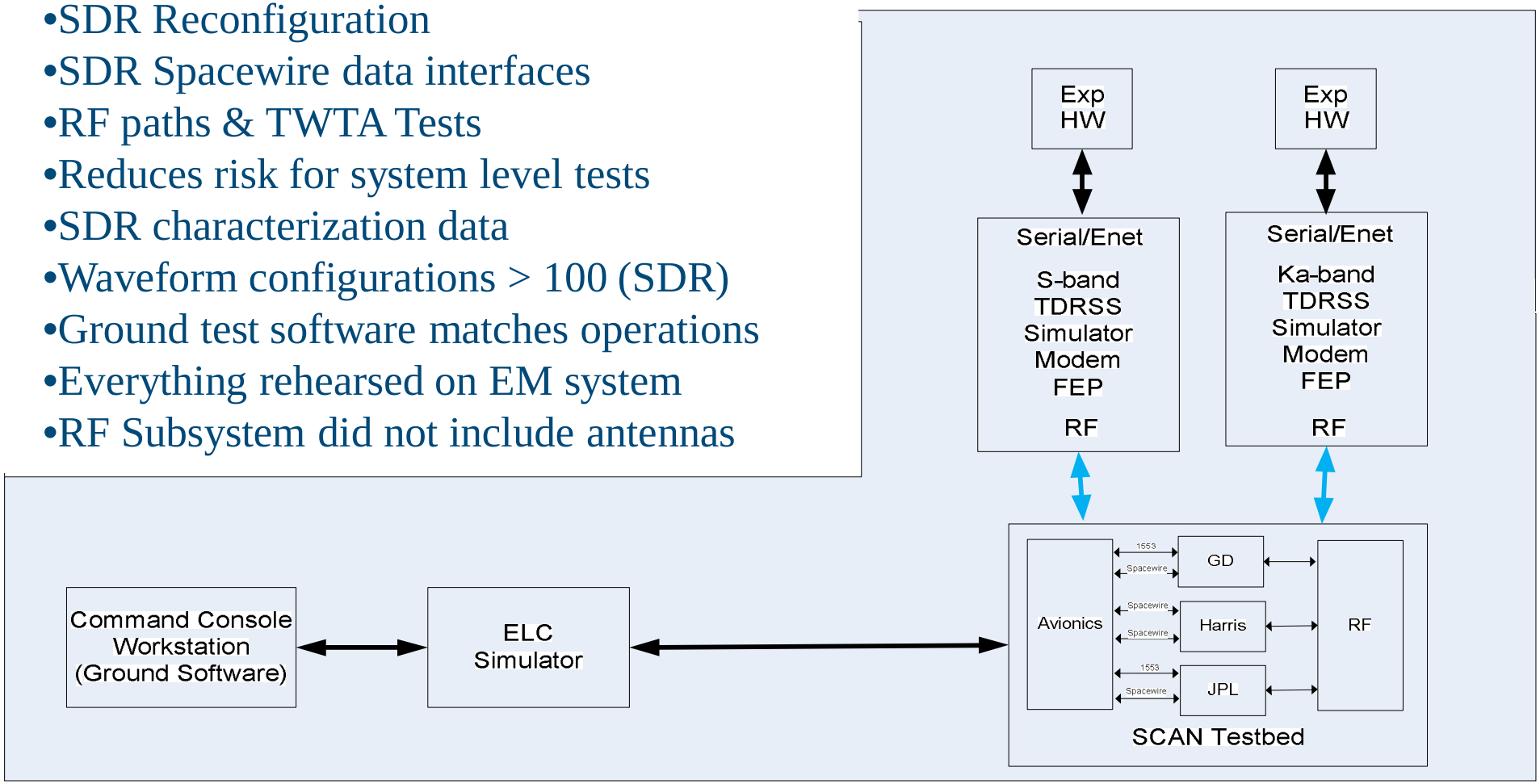
SDR Communications System Tests mixed among Environmental Tests

SDR Verifications: Thermal and Performance

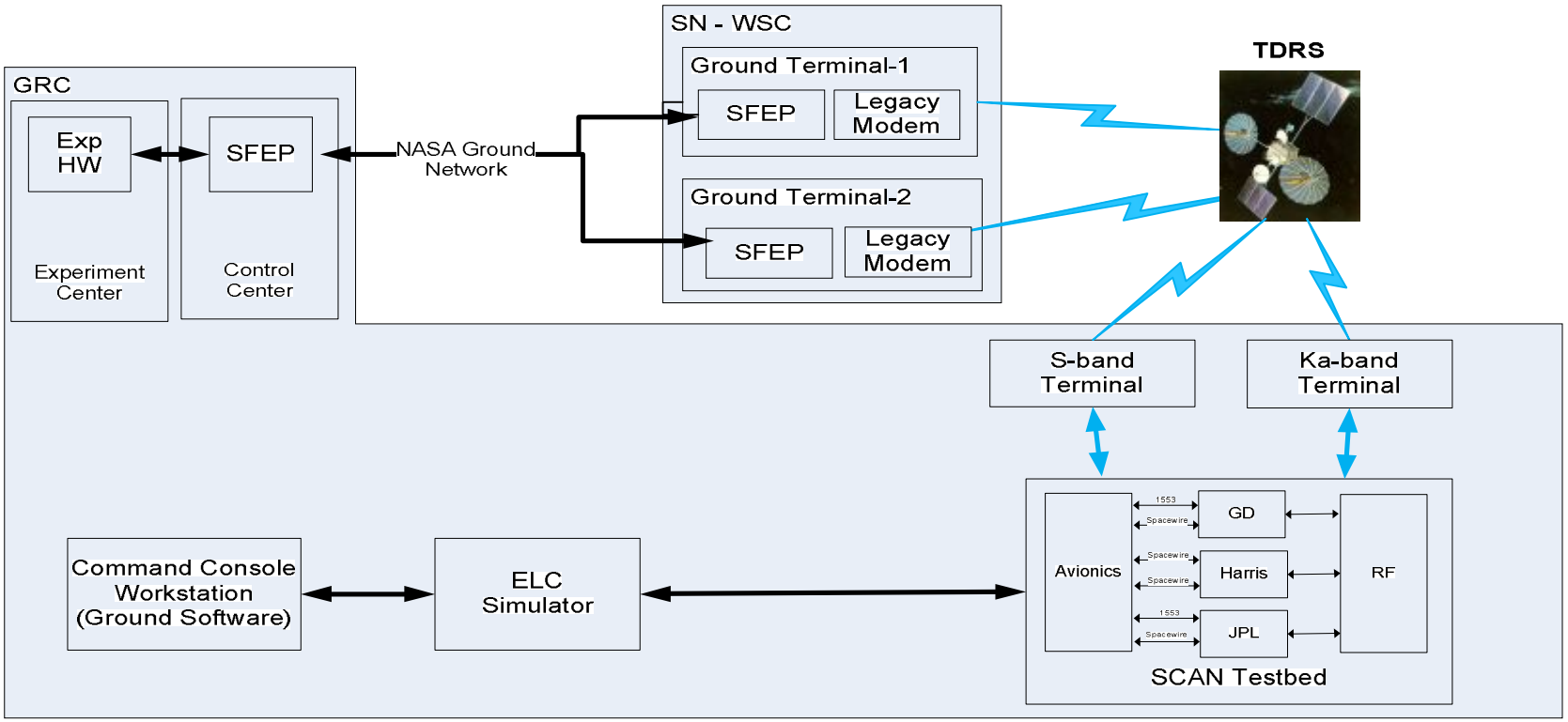
- Plan tests for both application requirements & SDR characterization
- During platform development, require test waveforms for characterizations at system level (and box level)
  - IF interface on the SDR was helpful for JPL SDR system tests
- Thermal
  - Characterize platform aspects, especially when not able to characterize without waveform
    - Vector modulators in JPL SDR
    - Amplifier power (temperature compensating circuits)
    - Analog AGC, digital AGC, NF
    - Ka-band output (TWTA + SDR)
- Performance Test (SDR Applications (Waveforms) – Comm Functions)
  - Minimum Signal Level Tracking/Acquisition Threshold
  - Acquisition Time, False Lock susceptibility
  - Coded and Uncoded BER performance
  - Operating Frequency Control, Frequency Tracking Range
  - Transmitter Output Spectrum/Spectral Mask
  - Carrier Suppression
  - Characterized path from each antenna port to the radio
  - Performance in presence of interring carriers and other PN codes

SDR & Communication System Test

- Tests signaling, modulation, data formatting
- SDR Reconfiguration
- SDR Spacewire data interfaces
- RF paths & TWTA Tests
- Reduces risk for system level tests
- SDR characterization data
- Waveform configurations > 100 (SDR)
- Ground test software matches operations
- Everything rehearsed on EM system
- RF Subsystem did not include antennas

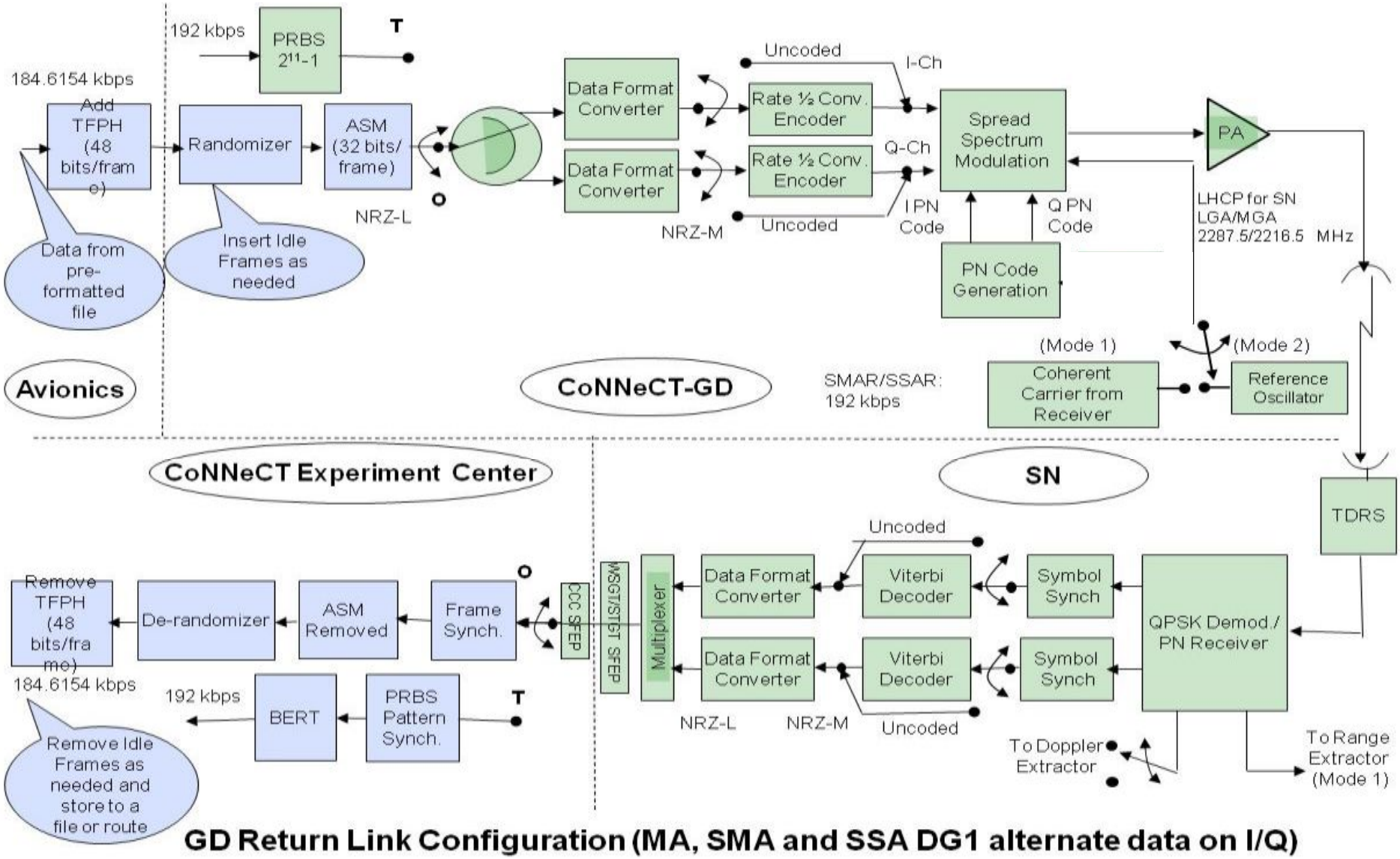


SN Compatibility Test, TDRSS Relay Link



- Demonstrates system in "test as you fly" configuration
- Uncovers incompatibility and configuration issues throughout the system
  - System configurations: 400-500 (SDR, FS antenna, SN)
- Pre-launch performance data
- RF Subsystem did not include antennas

Functionality of typical GD Return Link



GD Return Link Configuration (MA, SMA and SSA DG1 alternate data on I/Q)

SDR Verifications

- Identify early which SDR capability beyond mission requirements to include in requirements set
  - Amplifier characteristics (IF gain, I/Q balance to RF)
  - Temperature characteristics (digital and RF)
  - Trade verifications of essential mission requirements, while characterizing overall performance
- Manage Complexity!
  - Reconfigurable options (coding, framing, data rate, frequency) + mission configurations (payload antenna paths, TDRSS services) == 100's of configurations to manage.
- Changing the culture of verifications for space
  - Unable to test everything on ground before flight
  - Testbed designed to fly new flight configurations with verifications on ground hw only

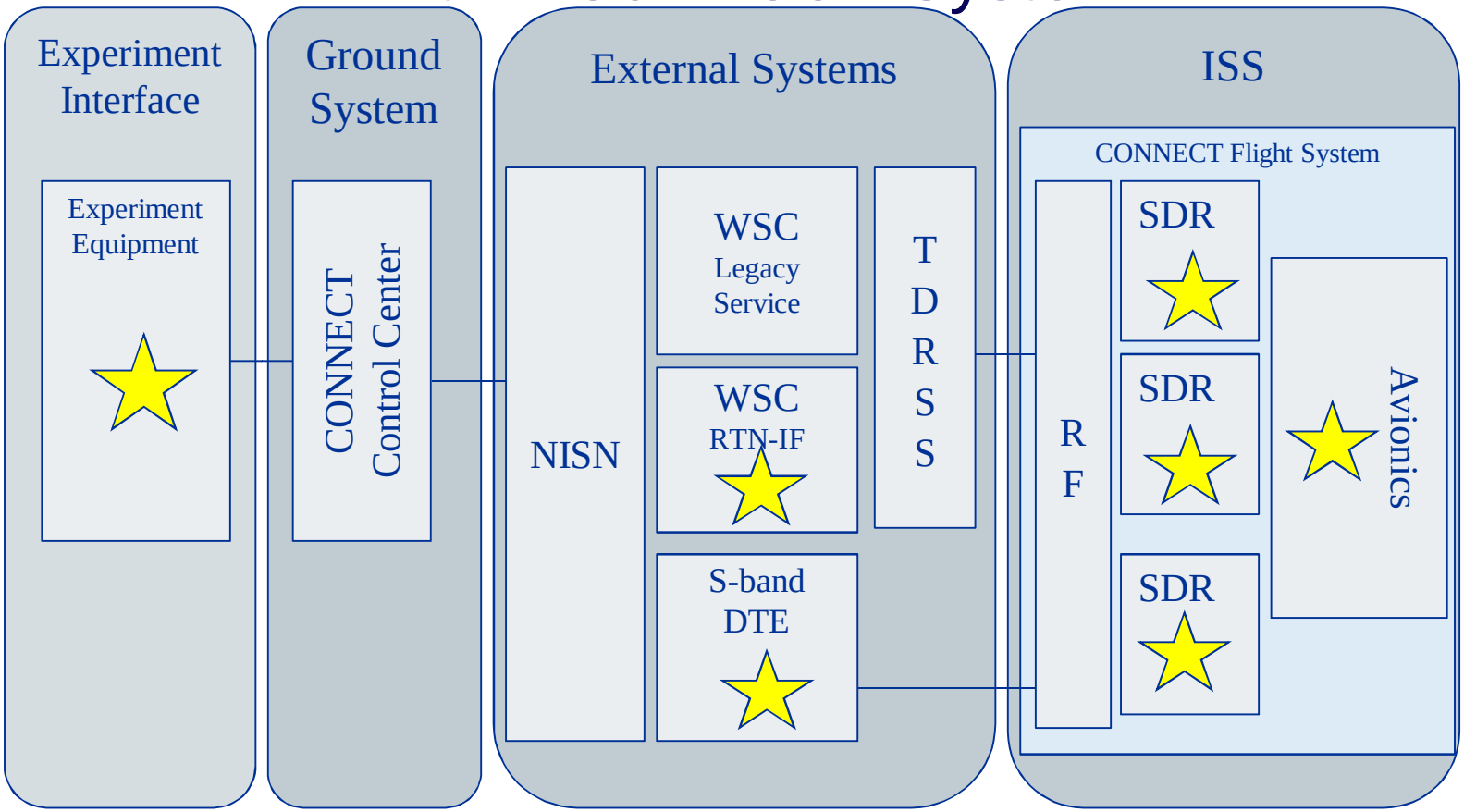
SDR Development & Verification Conclusions

- SDR Development & Verifications
  - Spend systems engineering time on the SDR itself to separate platform and waveform aspects
    - Provide both platform and waveform requirements
    - Balance mission requirements with potential SDR reprogrammability capability
    - Understand platform performance for future waveform developers
    - Good documentation set
  - Divide test plan between platform and applications (Testbed requirements did not address full capability of radio, but rather concentrated on link functions)

- Experiment Opportunity for Academia and Industry
  - Develop/test applications and concepts– expect experiment call in mid 2012
    - Comm waveform development and operation in space
    - SDR-based mission concepts of operations
    - Networking experiments using avionics as router between SDR nodes
    - GPS-based navigation waveforms
  - Prove out STRS among multiple SDRs in space environment
  - Scheduled for launch in mid 2012

Backup

Experimenter Access Points within CoNNeCT System



★ = Experiment Element (e.g. sw, fw, hw, component)

Experimenters have access to
Flt SDRs, avionics, Gnd SDR, various ground points

SCAN Testbed Flight System Configuration